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Multi-scale analysis of solar incidence and transmittance in Palestine: Annual, monthly, and daily assessment using simulation tools

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ABSTRACT

This study presents a hierarchical multi-scale assessment of solar incidence and solar transmittance in highly glazed buildings under the climatic conditions of Palestine. Using Design Builder with EnergyPlus weather data for Jerusalem, the research evaluates how facade orientation, window-to-wall ratio, and glazing type influence solar heat gains at annual, monthly, daily, and hourly levels. A reference office space with a single-glazed facade was simulated across four orientations and five window-to-wall ratios, combined with six glazing systems ranging from single clear to advanced low-emissivity and solar control glass. Annual and monthly simulations were first used to identify critical peak solar gain periods for each orientation. These peak months were then examined through detailed daily and hourly analyses to capture short-term fluctuations often masked by averaged data. Results show that solar gains increase almost proportionally with higher glazing ratios across all orientations. However, the timing and intensity of peak gains strongly depend on orientation. South facades exhibit predictable midday peaks, east and west facades experience sharp morning and afternoon peaks due to low-angle solar radiation, and west facades record the highest overall peak gains. Even north facades, often considered thermally neutral, demonstrate noticeable gains at high glazing ratios. Glazing type plays a decisive role, with single clear glass producing the highest transmitted gains, while double low-emissivity and solar control systems reduce peak transmission by up to about fifty percent. The study concludes that combining long-term simulations with detailed peak day analysis provides a more accurate understanding of solar gain behavior in Mediterranean and hot climates. The proposed multi-scale methodology offers practical guidance for optimizing facade design, glazing selection, and energy-efficient building envelopes in regions with high solar availability.

Keywords: solar incidence, solar transmittance, window-to-wall ratio, glazed facades, building energy simulation.

INTRODUCTION

The window-to-wall ratio (WWR) is one of the most important factors that determine the thermal performance of a building's facade. It shows the proportion of the total window surface area to the total exterior wall surface area. The impact on solar heat gain is immediate (Ma'bdeh et al., 2025). The correlation between (WWR) and solar gain is one of direct proportionality. An increase in the WWR will mean that a corresponding increase in the amount of solar radiation entering the building through the windows will occur, and consequently, there will be higher solar gain. The reason for this is that a larger window area will let more light through, which can result in an increase in the heat gain by the building (Mustafa et al., 2024).

The type of glazing applied to windows in buildings further affects the amount of solar energy transmitted into interiors. Single clear glass is the highest solar beam and daylight transmitter, while reflecting and shading with tinted and double-glazed glass can detrimentally affect the light coming into the building but not significantly so if one applies advanced glazing technologies of low-emissivity (low-e), reflective, and spectrally selective coatings (Al-Harbi et al., 2023).

The position of the facade affects the WWR and glazing type to create unique solar gain patterns. The southern facades in the Northern Hemisphere receive the highest midday solar radiation when the sun is at its highest, while the eastern and western orientations have more pronounced solar gains in the morning and in the afternoon, respectively. The north-facing walls are for the most part, excluded from the direct sun but still get some diffuse sky radiation, particularly when WWRs are high (Aydınol & Ayyıldız, 2025).

Solar radiation is a key factor in evaluating the thermal and energy performance of buildings, which get the most input through their large glass fronts. Glazing provides increased light and comfort, but at the same time is the most significant channel for solar heat gains, which can result in high cooling energy consumption in warm and Mediterranean climates (Szokolay and Gokhale, 2014). Thus, the correct calculation of solar incidence and solar transmittance is necessary for the comprehension and management of solar gains in the design of modern buildings.

Solar incidence is the quantity of solar radiation that hits the building skin, and it is different for east, west, north, and south facades. Also, it is dependent on the geographical location, time of the day, and season, while solar transmittance is the fraction of the solar radiation incident on the coating that gets transmitted into the indoor space. These two aspects are very much dependent upon the weather conditions, the clearness of the atmosphere, and the changes in solar radiation from day to day and hour to hour. Glazing with high transmittance takes full advantage of passive solar heating, but it might still be a problem during the hottest part of the day when the sun is at its peak, whereas low transmittance ones (like low-emissivity coatings, spectrally selective glass, and reflective layers) are made to either block or reflect a great deal of incoming solar energy, thus decreasing SHGW and the loads put on cooling systems. In places like Palestine, where there is a lot of sunshine, and this is combined with different seasons and daily hot/cold periods, these aspects become very important for buildings with a lot of glazing.

Solar radiation and solar gains have been assessed by most previous studies in terms of monthly or annual average values, which give a good understanding of long-term trends but often miss out on the short-term peaks that are responsible for building overheating and cooling loads (Duffie and Beckman, 2013). The daily and hourly fluctuations in solar incidence and transmission, caused by solar position and atmospheric conditions, may lead to very high solar gain events that are not properly represented by the average values. This limitation is of particular importance in the case of glazed Facades, where peak solar gains usually set the limits for thermal discomfort and system sizing.

Shadid et al. (2023) investigatedhow weather conditions and dust accumulation affect the performance of different photovoltaic systems installed on campus. Using experimental monitoring, the authors analyze variations in solar radiation, temperature, and soiling impacts on power output. The results show that environmental factors, particularly dust and seasonal changes, significantly influence energy production and system efficiency. The study emphasizes the importance of accurate solar performance assessment and maintenance strategies in regions with high solar exposure and dusty climates.

Chen et al. (2025), indicated that one of the primary problems modern glass buildings face, owing to their architectural features, is solar radiation. These buildings consume a lot of energy, often just to maintain the optimum comfort levels for the people residing in them. The authors applying the PMV method for simulating actual human perception reveal that it is necessary to drop indoor air temperatures by 3.5 °C at the most, which results in a phenomenal 28% hike in power usage. Eventually, the research favors indoor shading methods as the key means to lessen the effect of heat radiation, thus even providing more effective climate control at the cost of significantly less energy wastage.

At the same time, Vitale et al. (2020) came up with a theoretical edifice that helps to enhance the energy efficiency of buildings through the better consideration of the complicated sky conditions and cloud cover. The authors have scanned the parameters and conditions for the global solar transmittance in vertical glass windows through various angles and variable levels of diffuse radiation. Using outdoor data from Uruguay spanning over three years, the authors have put to the test three different mathematical models that are used for predicting the amount of solar energy transmitted through a layer of common float glass. The research brought to light that although the performance of the models is at a very high level when diffuse irradiance is measured directly, when these values are only estimated, their error rates are increased three times. Furthermore, the results show that the seasonal variation in ground reflectivity, or albedo, has a considerable effect on the light levels reaching vertical surfaces.

A special type of calorimetric method introduced to estimate the g-value or total energy transmittance of glazing systems directly at the site of the building in order to evaluate the building's performance. The method consists of positioning a water-filled calorimeter behind a window to quantify the heat gain due to solar radiation, taking into consideration complex parameters such as angle of incidence and diffuse sky radiation. These in situ measurements comparised with a mathematical model and the reduction of energy flux deviations yields a practical replacement for costly laboratory tests. This method is especially important for ascertaining whether the overheating or high cooling demand is due to the building's envelope or its mechanical ventilation systems (Goia and Serra (2018).

In another research, Rodríguez-Muñoz et al. (2023), delved into the question of whether or not the use of a sophisticated anisotropic model for diffuse solar radiation resulted in a substantial upgrade in the solar transmittance calculation for building glass over the standard and simpler isotropic assumption. The authors, by contrasting experimental data from both horizontal and vertical glass specimens in Uruguay with theoretical models, assessed the extent to which different sky conditions (from clear to overcast) influenced the precision of energy gain estimates. The findings point out that, though an anisotropic approach provides minor adjustments under clear skies, it does not offer any major benefits in overall building performance simulations because of the measurement and transposition uncertainties that are present. Hence, the study concludes by declaring the conventional isotropic model to be the most useful and dependable option for the majority of architectural energy simulations.

The article of Bustamante et al. (2014) study aims at the investigation of external shading devices (ESDs) and their effects on thermal and lighting environments in office buildings in the warm, arid climate of Santiago, Chile. The authors assess the good performance of the complex fenestration systems in reducing overheating and glare by measuring solar radiation and daylight transmission simultaneously in three different architectural cases. The study indicates that whereas the automated external roller systems offer a uniform and top-notch control, some other fixed designs, such as the undulated perforated screens, may suffer from design flaws leading to the occurrence of unwanted peaks of light and heat. In the end, the paper asserts that to succeed in getting the dual goal of occupant comfort and energy efficiency, a sophisticated design approach is needed that takes into account the changing solar angles rather than simply relying on daily performance averages.

The accuracy of glazing behavior, thermal properties, calculations, and monitoring is studied by many researchers. Among them is Lu et al. (2017), who look into the accuracy of solar heat gain coefficient (SHGC) computations specifically in the context of glazing Facade buildings where standard assumptions might not apply. The researchers claim that while conventional models consider all entered solar radiation as being absorbed by the room, glass-heavy modern buildings let a great part of the light come back through the windows after reflecting off the internal surfaces. Through the application of mathematical modeling and iterative algorithms, the research indicates that the actual heat gain is less than what was thought before, thus requiring a new SHGC to be used to avert the overestimation of a building's cooling load. The results emphasize that the dimensions of the room, mainly depth and height, and the absorptance of the floor are the most important factors determining the revised energy calculations.

In the work done by Wolfertstetter et al. (2020), it is revealed that the monitoring precision of solar energy is greatly influenced by the angle of incidence and the diffuse radiation measurement when the dust accumulation on the panels is considered. Automated sensors like DustIQ which are traditionally used for testing, give readings that are consistent irrespective of the sun's position; however, they usually do not correlate with the daily power loss patterns of the actual photovoltaic cells, where the impact of soiling becomes sharper as the sun hits the glass at sharper angles. The authors, therefore, came up with an adaptation method using Linke Turbidity and solar geometry to correct sensor data, which virtually reproduced the optical behavior of soiled modules under both clear and cloudy skies. This mathematical correction not only helps plant operators to avoid overestimation of energy production but also results in more accurate performance evaluation and hence inexpensive maintenance strategies in dusty areas.

Wong and Eames (2015) presented a numerical modeling method that evaluates the optical performance of transparent insulation systems (TIs) used for building facades. The specific arrangement of the authors' research is the use of polymethylmethacrylate (PMMA) capillary cells placed between the two glass panes, and meticulously counting how solar radiation meticulously how it is transmitted, absorbed, and reflected at different incidence angles. The comprehensive study provides a prediction of energy efficiency by employing mathematical principles such as Snell's Law and Pascal's Triangle to monitor the interactions of light in the capillary structure. In the end, the authors' work fills a void in the current literature by looking at the whole multi-layered system instead of just the insulating material, thus providing a trustworthy instrument for the optimization of sustainable building design.

Fawaier et al. (2024) analyzed heat transfer mechanisms and wall heat loss recapture in transpired solar collectors using CFD and experimental validation. The study demonstrated how solar-driven heat transfer processes significantly influence building thermal efficiency, emphasizing the importance of accurate modeling of solar incidence and thermal interactions in Facade-related systems.

Li et al. (2023) investigated the use of photovoltaic systems integrated into building facades (BIPV) as a source for solar energy in Hong Kong, highlighting the application of semi-transparent skins as a means of improving energy efficiency. A modern climatic analysis for the support of net-zero-energy building (NZEB) designs is provided through the authors' application of real-time measured solar radiation and daylight data for the years 2019 to 2020. The research considers the impact of various building orientations and architectural parameters – such as the window-to-wall ratio and daylight-linked lighting controls – on total energy performance. The study concludes that, in the case of new buildings, the installation of BIPV on the whole building skin can produce usable electric power and, at the same time, contribute a lot to cooling and lighting energy saving, especially in the case of high-rise subtropical urban environments.

Fortunately, building energy simulation tools come up as an efficient method to eliminate this limitation since they allow dynamic, time-resolved analysis of solar radiation and its interaction with building envelopes. Design Builder DB, which employs Energy Plus as its simulation engine, makes it possible to represent in detail solar incidence, glazing transmittance, and resultant solar gains under realistic climatic conditions. Although these tools are widely used, there is still a shortage of research conducting a structured multi-scale approach that connects annual simulations with daily analyses of peak solar gain conditions, especially in the Palestinian climatic context.

Thus, the objective of this research is to assess solar incidence and solar transmittance on glass building Facades in Palestine using the Design Builder simulation and a hierarchical multi-scale methodology. The analysis is performed at the annual and monthly levels to pinpoint the critical times of very high solar gains, and afterward, a thorough daily and hourly assessment of a representative peak solar gain day is conducted. By combining long-term simulation results with short-term detailed analysis, the research aims to provide a solid understanding of solar gain behavior in glazed buildings and to guide design decisions for energy-efficient building envelopes in other areas with similar climates.

METHODOLOGY

This research utilizes a simulation-based quantitative method to measure the amount of solar light that hits and passes through glazed buildings with respect to the specific climate of Palestine. A hierarchical multi-scale approach was adopted, resulting in year and month analysis first, then day and hour investigation of the peak solar gain conditions. This structure provides both long-term typicality and high-resolution insight into the main solar performance periods. The present study refers to the simulation data for hourly solar incidence and transmittance. The data, which is representative of the peak gain months for each orientation, makes it possible to conduct a comparative study on how facade parameters control the incident and transmitted solar energy and thus the sensible load, during daily cycles.

Simulation tool and climatic data

The simulation software Design Builder DB was applied as the main analytical tool because of its proficiency in creating a dynamic energy performance of buildings and simulating solar radiation interaction with building materials. It works as a visual interface for the Energy Plus simulation engine, thus allowing for hourly computations of solar incidence, glazing transmittance, and solar heat gains. Climate data that are typical of the Palestinian area were introduced by means of an Energy Plus Weather (EPW) file. For this study, the reference weather station is Jerusalem station as it is the nearest station to the selected location and has almost the same weathering Data. Thus, making sure that solar radiation, temperature, and atmospheric conditions were realistically depicted all year round.

Building model and glazed facade configuration

A building model that accurately depicts the modern glazed constructions was created by means of Design Builder. The reference building model consisted of disclosing the geometric aspect in detail, as an office space with one side glazing (glass facade), dimensions of 4×4×3 m, and a total footprint area of 16 m^2 as shown in Figure 1.

The orientation of the facade and the distribution of glazing are clearly defined in Figure 2. Different facade orientations (north, south, east, west), WWRs (20%, 40%, 60%, 80%, and 100%), and six glazing configurations (single clear, single low-e, double clear, double low-e, Stopsol, and Synergy glass) are examined.

Glazing characteristics were determined by their solar and thermal performance parameters, like solar transmittance, and overall thermal properties, which enabled precise simulation of solar radiation passing through and the energy gains that resulted, as shown in Tables 1 and 2. The assessment was centered on the glazed facades' performance, which was the main factor contributing to the solar heat gains.

Annual simulation and monthly solar gain evaluation

Annual simulation was done for window exterior solar gain WESG to produce not only solar

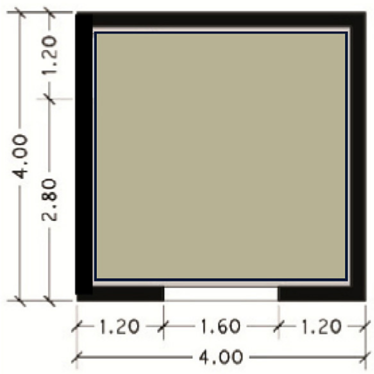

Figure 1. Geometric model of the reference office space with a single glazed façade used for the DesignBuilder simulation

Table 1. Thermal characteristics of single clear glass

	Glass type	Conductivity W/m·k	SHGC	Direct solar transmission	Light transmission	U-value W/m^2	Cost/area ILS/m^2
Single clear (Sg cl)	cl 6 mm	0.90	0.810	0.775	0.881	6.12	585.138
	low(e2=.2) cl 6 mm		0.71	0.68	0.811	4.233	702.165

Table 2. Thermal characteristics of double clear glass

	Glass type	Outer pane 6 mm pos.2	Inner pane	SHGC	Direct solar transmission	Light transmission	U-value W/m^2	Cost/area ILS/m^2
Double clear (Dbl cl)	Dbl cl	clear	6 mm cl	0.679	0.604	0.781	2.708	877.706
	Low E	Low cl	6 mm cl	0.563	0.474	0.745	1.77	936.22
	Sunergy	AGC sunergy	3 mm cl	0.549	0.45	0.611	2.679	585.137
	stopsol	AGC stopsol	3 mm cl	0.468	0.403	0.35	2.695	585.138

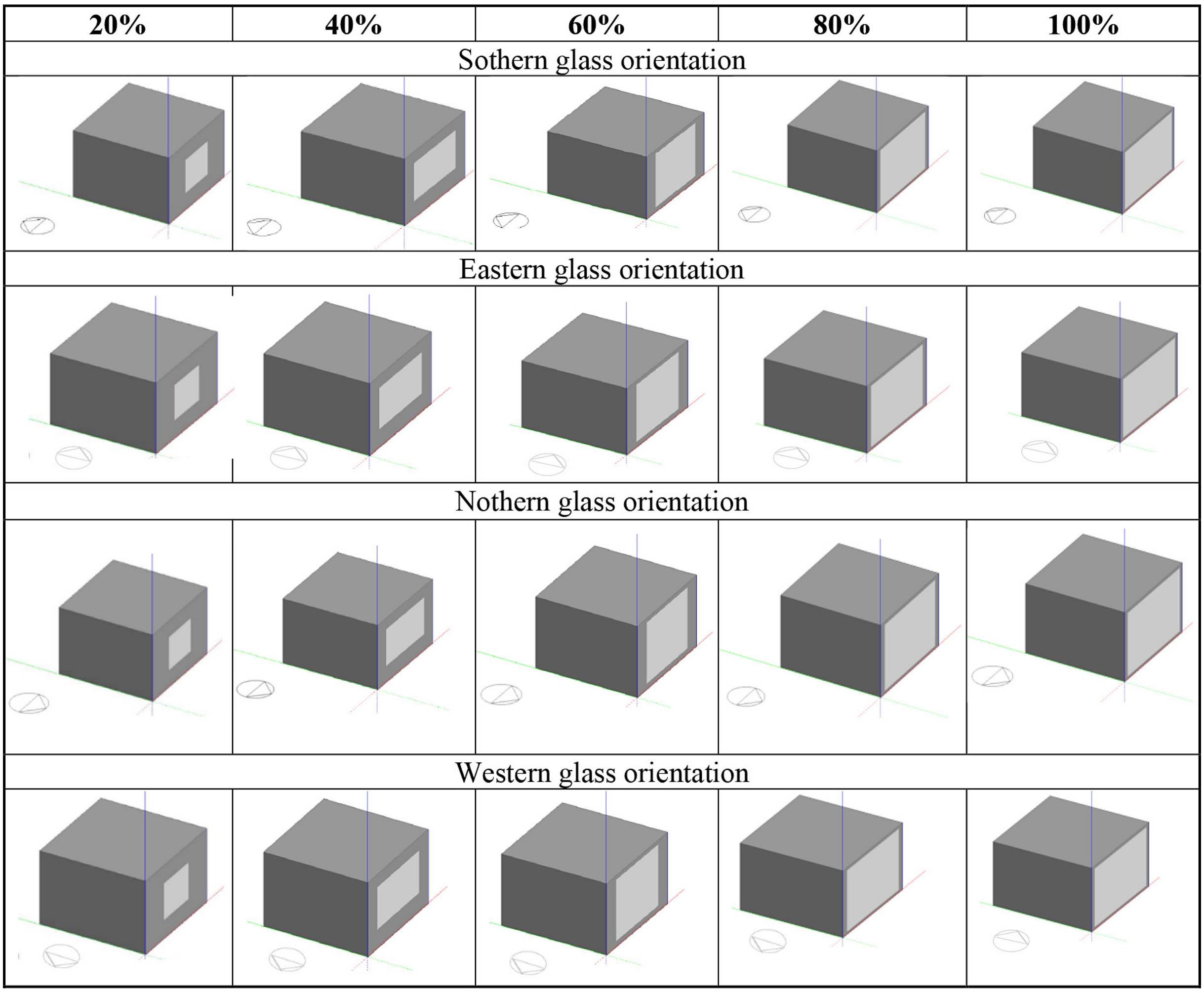

Figure 2 . Window-to-wall area ratio used in building and room simulations

radiation but also energy performance data for every single month of the year. The outputs of the simulation provided the monthly values of solar incidence and solar transmittance, which were then employed to determine the monthly solar gains that were received through the glass-walled buildings. The analysis in this part was able to indicate the total seasonal pattern of solar gains and at the same time to point out the periods when there was a lot of solar exposure.

Identification of critical solar gain periods

The monthly simulation outcomes were the basis for identifying the months with the highest solar gains through the glazed facades as critical periods. The selection of these months was not based on any seasonal assumptions but rather on quantitative comparison of the simulated solar gain values. This objective selection process made sure that the subsequent detailed analyses were concentrated on the periods that were most significant to the thermal performance and energy demand of the building.

Daily and hourly analysis of peak solar incidence day

During the chosen crucial month, one day that had the highest solar incidence was picked for thorough investigation. The daily solar incidence and solar transmittance were examined hourly to monitor short-term fluctuations and peak conditions. This study made it possible to determine the hours of maximum solar incidence and their connection with the position of the sun and the exposure of the facade. The approach is justified by the fact that it works on a peak day that is selected from the annual simulation results instead of choosing a day randomly, thus giving a realistic evaluation of the extreme solar performance conditions in buildings with glazed surfaces.

Methodological scope and limitations

The adopted methodology is capable of giving a detailed evaluation of solar incidence and solar transmittance across several temporal scales; nevertheless, there are still some restrictions. The dependencies on representative climatic data and assumptions that are part of the simulation-based modelling are among these. Still, the approach has a very strong and solid ground for the analysis of the solar gains in the glazed facades, and it also allows for similar assessments and comparisons in different climatic contexts that are design-oriented and supportive of the analysis.

RESULTS AND DISCUSSION

Annual and monthly identification of peak solar gain periods

The yearly simulation results showed significant seasonal changes in the incidence and transmittance of solar energy on all facade orientations. By aggregating simulation outputs every month, it was possible to pinpoint the months with the highest solar gains through glazed Facades. The data suggest that the peak solar gain is not evenly distributed among the orientations but instead goes in line with the solar path and facade exposure.

The south-facing walls captured the maximum monthly solar gain in October, which was the consequence of a high solar position and less cloud cover in the transitional seasons. The east- and west-facing walls, on the other hand, had their solar gains mainly in July, which was the time of the year when there were long daylight hours and low-angle solar exposure during the morning and afternoon hours, respectively. Peak month solar gains for different WWR and glazing are defined in Tables 3–6. The north-facing walls, in contrast, had their maximum solar gains in June when diffuse radiation levels are at their highest due to long solar paths and bright skies. This scenario substantiates the need to take orientation-specific peak months into account while evaluating the solar performance of buildings with large glass areas.

Daily and hourly solar incidence and transmittance under peak conditions

Daily analyses were performed for typical peak solar gain days selected during the critical months for every orientation. Solar incidence showed a typical daily pattern over the entire building, which was made up of a smooth increase after the sun rose, then reaching the peak of the orientation of the facade, and lastly decreasing to the level of the sunset. The solar radiation, which was both incident and transmitted, showed a linear increase in proportion to the window-to-wall ratio (WWR), thereby verifying the great importance of the area of glazing in controlling solar heat gains.

The hourly profiles reveal that solar incident radiation begins to rise shortly after sunrise, reaching its maximum intensity, after which it gradually decreases toward sunset. This pattern represents the typical daily solar exposure (Table 7).

Table 3. South peak solar gain exterior window (kWh)

WWRS	Single clear	sgl cl low e	dbl cl	dbl cl low	dbl sunergy	dbl stopsol
20%	189.01	168.578	135.634	103.964	101.71	90.3669
40%	392.24	349.835	281.47	215.747	211.07	187.53
60%	600.21	535.327	430.713	330.142	322.985	286.964
80%	808.65	721.235	580.291	444.793	435.151	386.621
100%	986.68	880.014	708.041	542.714	530.949	471.735

Table 4. East peak solar gain exterior window (kWh)

WWRS	Single clear	sgl cl low e	dbl cl	dbl cl low	dbl sunergy	dbl stopsol
20%	148.64	131.893	108.43	83.485	81.0769	72.172
40%	308.45	273.705	225.02	173.249	168.252	149.772
60%	472	418.831	344.332	265.11	257.463	229.185
80%	635.92	564.283	463.912	357.177	346.875	308.777
100%	775.91	688.509	566.041	435.81	423.239	376.753

Table 5. West peak solar gain exterior window (kWh)

WWRS	Single clear	sgl cl low e	dbl cl	dbl cl low	dbl sunergy	dbl stopsol
20%	202.9	179.749	149.41	115.265	111.632	99.4344
40%	421.07	373.016	310.057	239.199	231.66	206.347
60%	644.33	570.8	474.458	366.029	354.492	315.758
80%	868.09	769.026	639.227	493.144	477.599	425.414
100%	1059.2	938.327	779.952	601.709	582.742	519.069

Table 6. North peak solar gain exterior window (kWh)

WWRS	Single clear	sgl cl low e	dbl cl	dbl cl low	dbl sunergy	dbl stopsol
20%	81.2	72.3874	56.4732	43.2872	42.3321	37.6596
40%	168.5	150.219	117.194	89.83	87.8481	78.1516
60%	257.85	229.869	179.333	137.46	134.428	119.59
80%	347.39	309.698	241.612	185.198	181.112	161.121
100%	423.87	377.878	294.802	225.969	220.983	196.591

Table 7. The typical daily solar exposure

Orientation	West	South	East	North
Peak month	July	October	July	June
Peak day	16	28	11	21
Peak hour	16:00	12:00	8:00	18:00

South facade

On the south side, the daily solar gains were very much focused around noon, with the maximum values always taking place from 11:00 to 13:00. The highest solar power hitting the building was about 1.77 kWh with 20% WWR, whereas with 100% WWR it went up to 8.58 kWh, which is almost five times the original amount. The same percentage increase was noted in the passed solar energy through all kinds of windows (Figures 3–7).

One layer of clear glass always showed the maximum solar transmittance and recorded the highest solar gain of up to 10.08 kWh at the maximum WWR of 100%, whereas the two types of low-e double and Stopsol glazing allowed the least solar entry into the building and thus, reduced the sunny side of the building by about 40–50%. The solar synergy glass was in the middle category as it had lower transmittance but still considerable solar penetration. The noon time peak is equally distributed and points to the solar altitude as the main factor for south-facing facades, and at the same time indicates how much the solar gains dependent on the glazing ratio and optical properties.

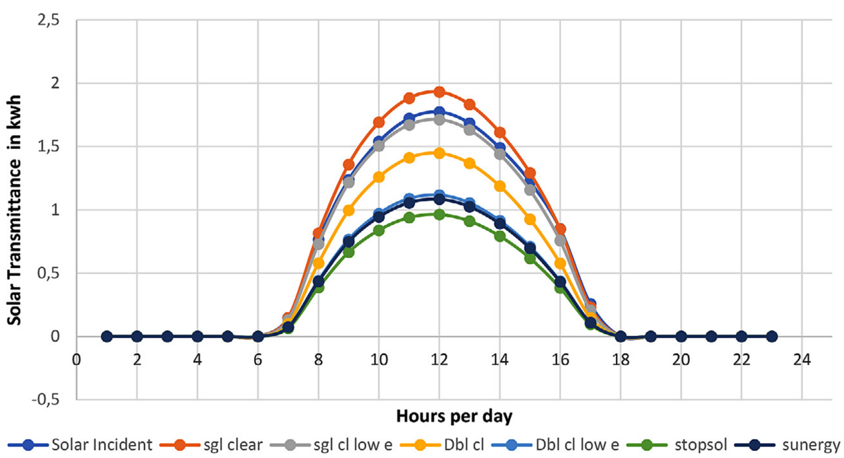

Figure 3. South facade daily exterior window gains for 20% WWR

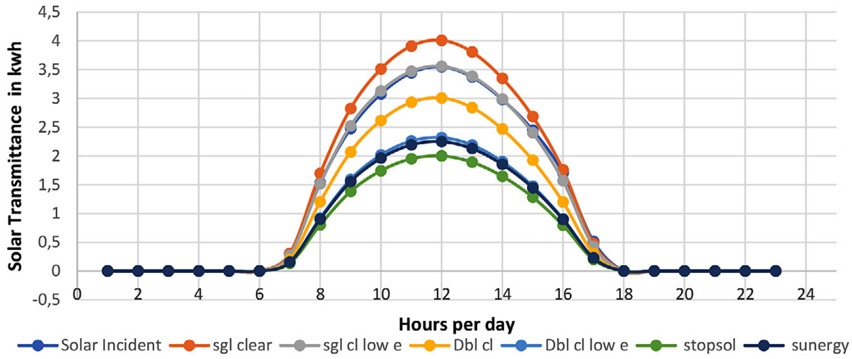

Figure 4. South facade daily exterior window gains for 40% WWR

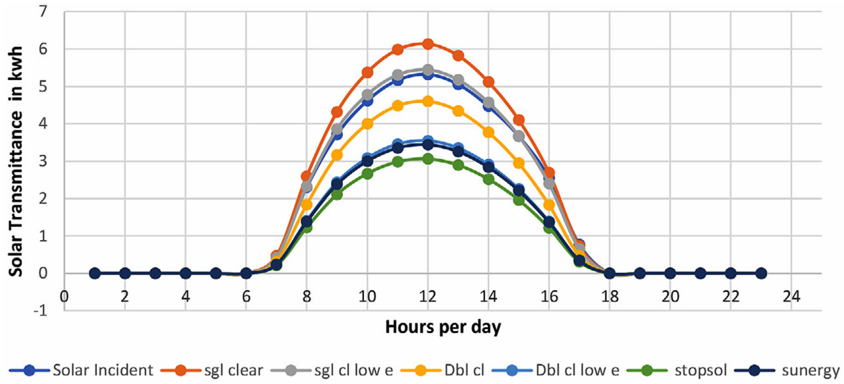

Figure 5. South facade daily exterior window gains for 60% WWR

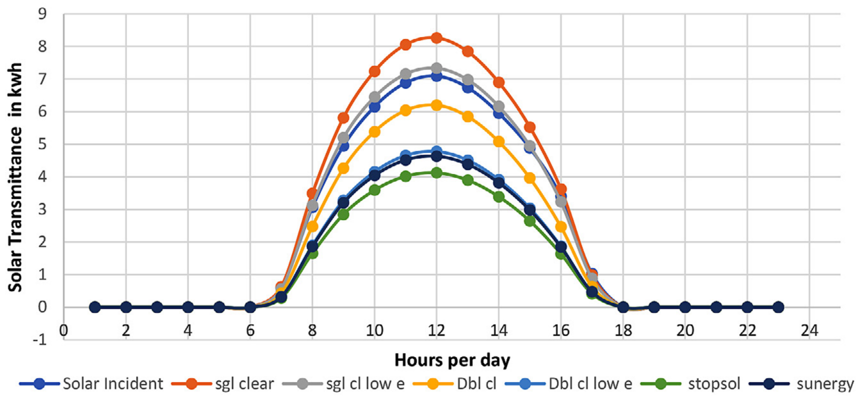

Figure 6. South facade daily exterior window gains for 80% WWR

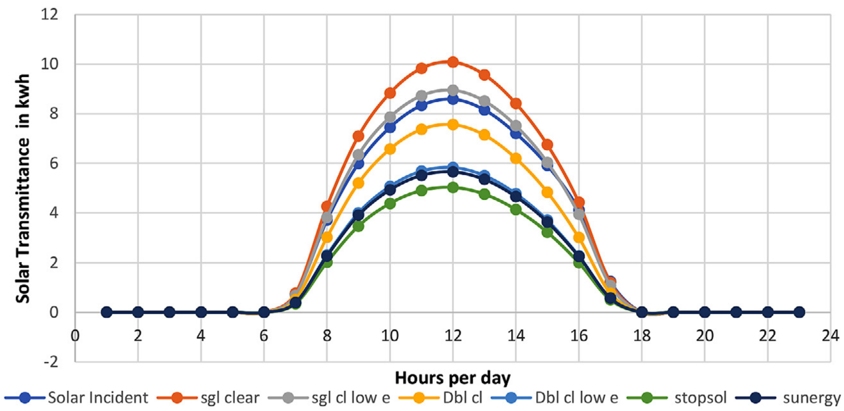

Figure 7. South facade daily exterior window gains for 100% WWR

North facade

The facades that faced north received much less solar energy than the other sides, mainly because the direct radiation was low and the diffuse radiation was high. The highest values were noted in the late afternoon at 18:00, especially in June. The maximum solar incident radiation at 20% WWR was kept under 0.71 kWh, while at 100% WWR it went up to around 3.42 kWh (Figures 8–12).

Even though the absolute values were lower, the type of glazing still had a significant influence. Single clear glazing always transmitted the highest percentage of the incident radiation, while

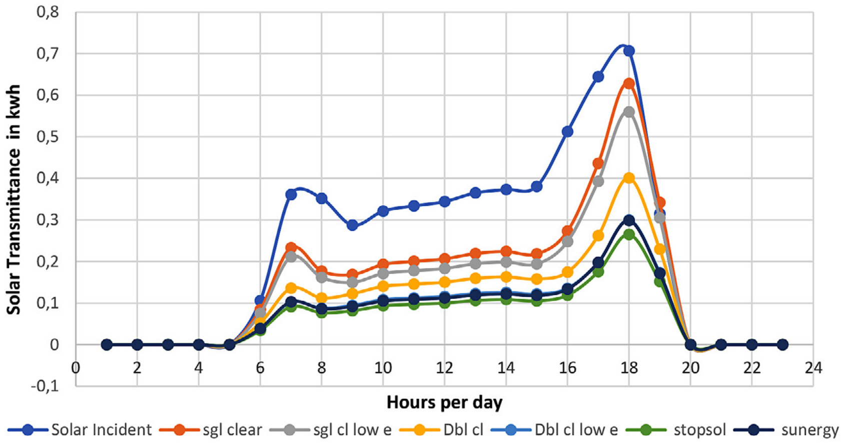

Figure 8. North facade daily exterior window gains for 20% WWR

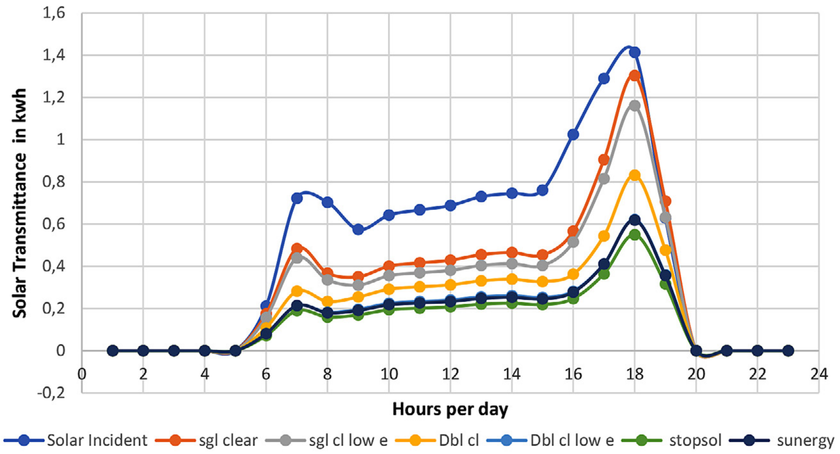

Figure 9. North facade daily exterior window gains for 40% WWR

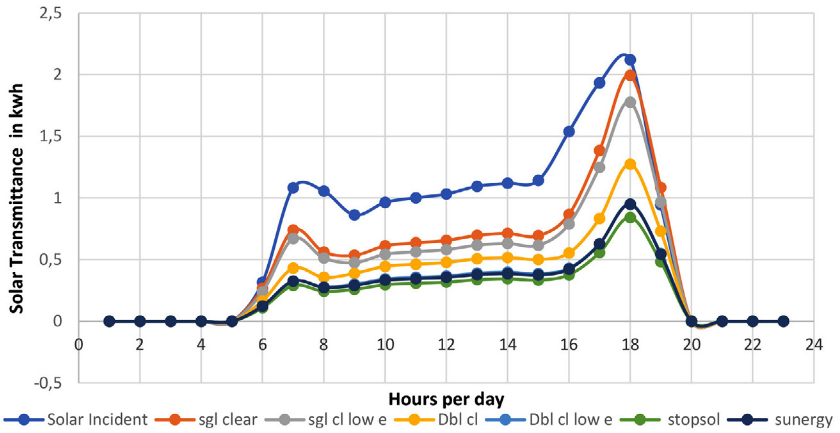

Figure 10. North facade daily exterior window gains for 60% WWR

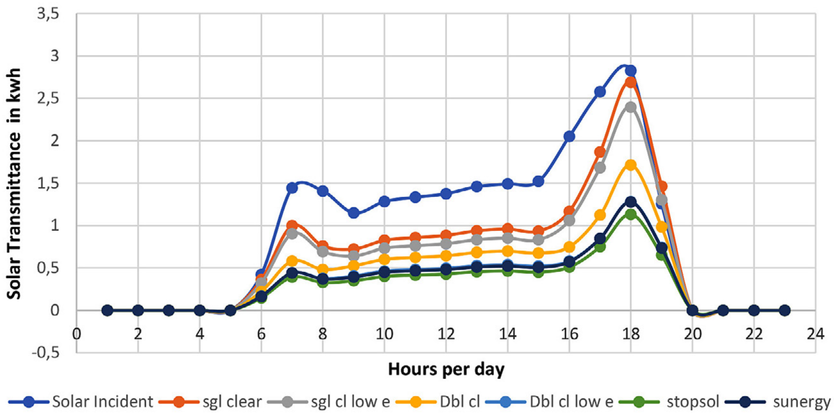

Figure 11. North facade daily exterior window gains for 80% WWR

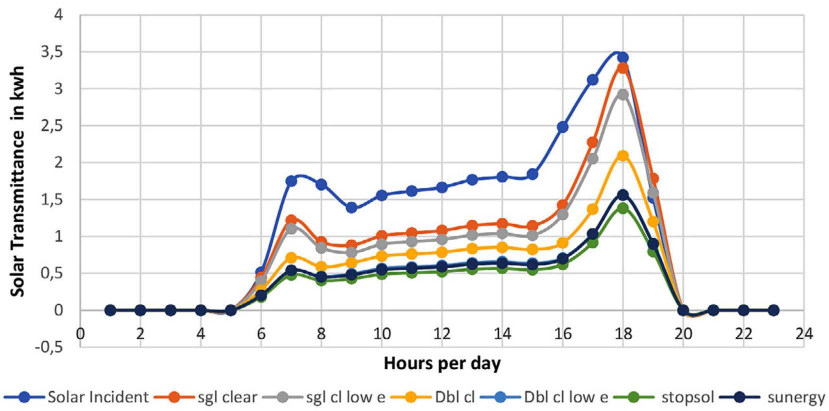

Figure 12. North facade daily exterior window gains for 100% WWR

double low-e and Stopsol glazing at the higher WWRs almost halved the transmitted gains. Such findings indicate that despite the fairly common assumption of north-facing Facades being thermally neutral, the increase in the ratio of glass to wall can still result in significant solar heat gains, especially in the case of long summer days and longer hours of sunlight.

East facade

The east-facing wall had a clear profile of solar exposure that was morning-oriented. There was a quick rise in the amount of solar radiation coming in after sunrise, and it was at its highest between 7:00 and 9:00, then it dropped sharply toward noon. With a 100% window-to-wall ratio, the solar radiation at its peak in the early morning was around 7.78 kWh (Figures 13–17).

The solar gains are transmitted very closely to this pattern. The solar energy admitted through the single clear glazing was the highest one, and it reached more than 9.40 kWh at its maximum, whereas Stopsol and double low-e glazing cut down the transmitted energy by about 45–55%. The synergy glazing kept the intermediate values and traded off daylight transmission with solar control. The results show that east-facing facades are particularly prone to intense short-duration morning solar gains, which can be a significant factor in cooling loads if they are not properly controlled.

West facade

West-facing facades got the highest peak solar gains of all orientations, especially in the late afternoon. The solar incidence was very low until noon and very high between 4 and 5 pm. When the wall-to-window ratio was 100%, the greatest solar radiation to hit the surface was about 9.14 kWh, which is the maximum value found for all orientations (Figures 18–22).

Daily peak hours

At the full glazing, transmitted solar energy through single clear glass reached more than 10.75 kWh, which shows that there was almost

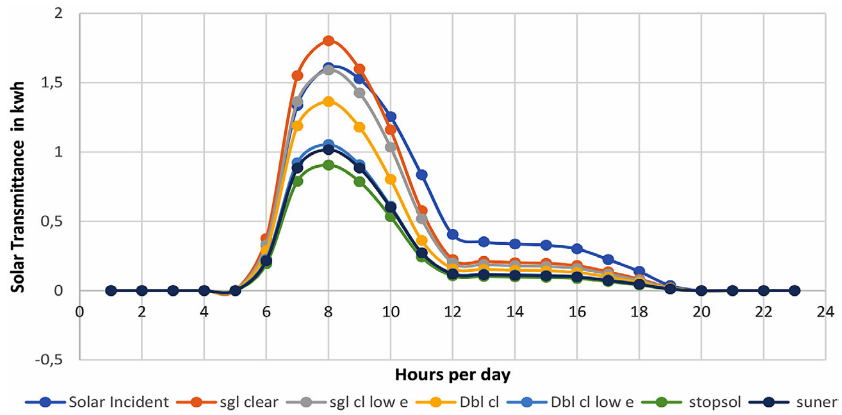

Figure 13. East facade daily exterior window gains for 20% WWR

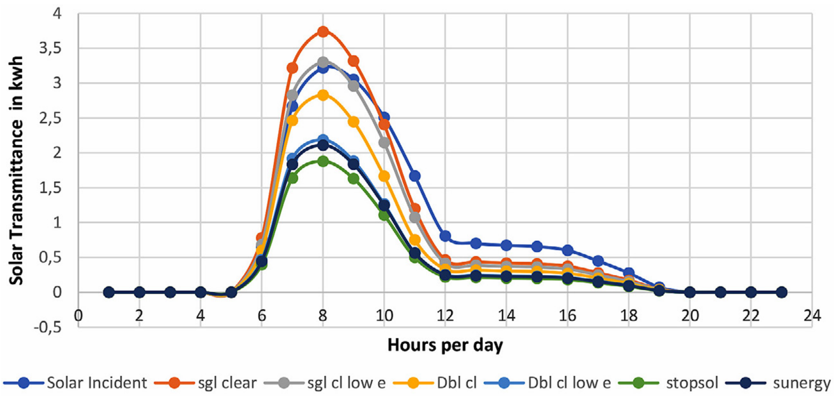

Figure 14. East facade daily exterior window gains for 40% WWR

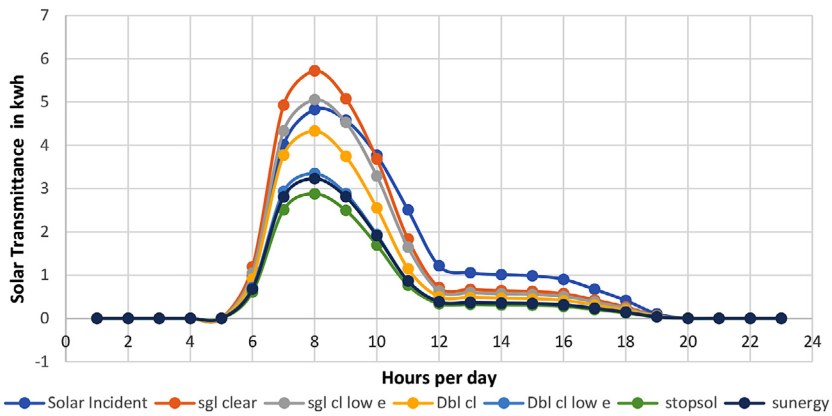

Figure 15. East facade daily exterior window gains for 60% WWR

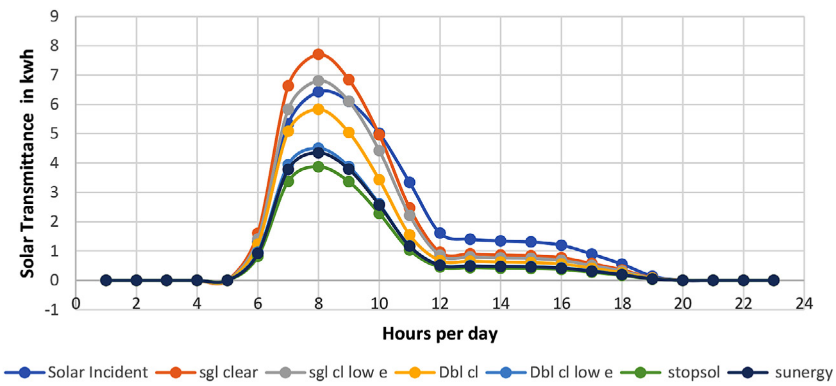

Figure 16. East facade daily exterior window gains for 80% WWR

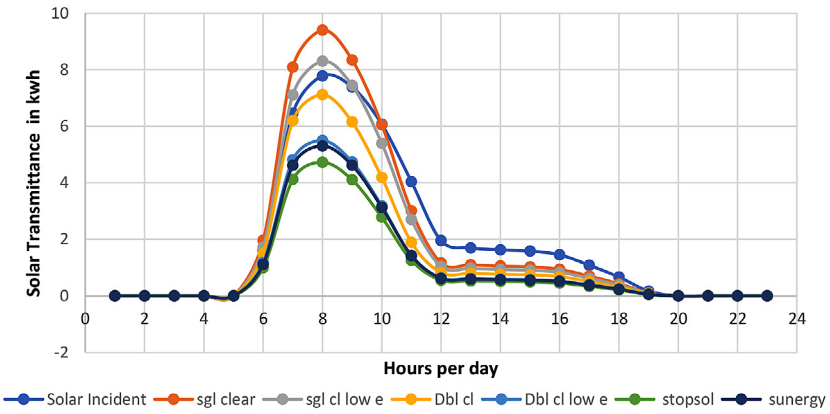

Figure 17. East facade daily exterior window gains for 100% WWR

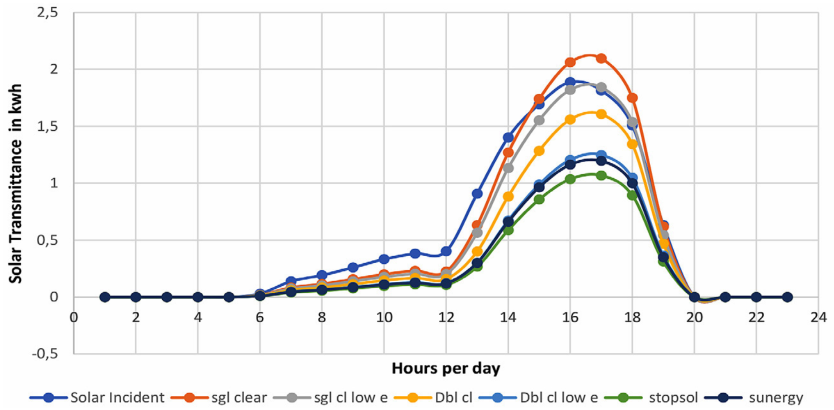

Figure 18. West facade daily exterior window gains for 20% WWR

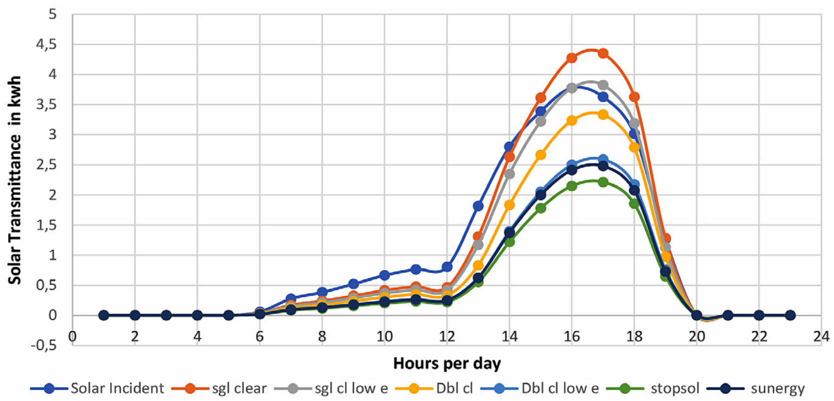

Figure 19. West facade daily exterior window gains for 40% WWR

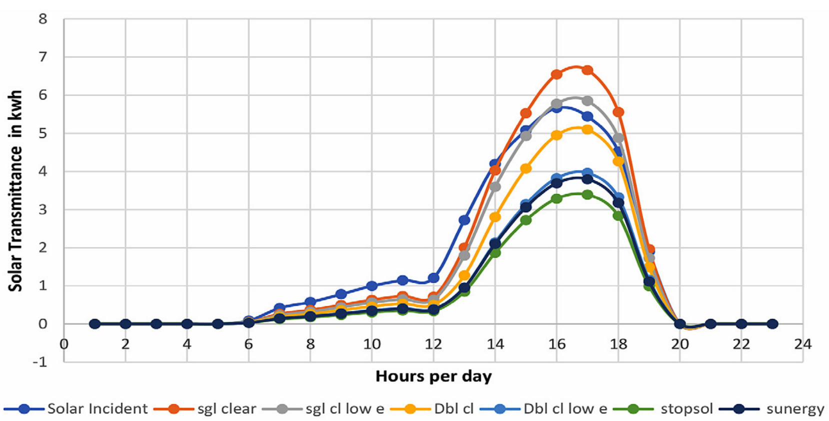

Figure 20. West facade daily exterior window gains for 60% WWR

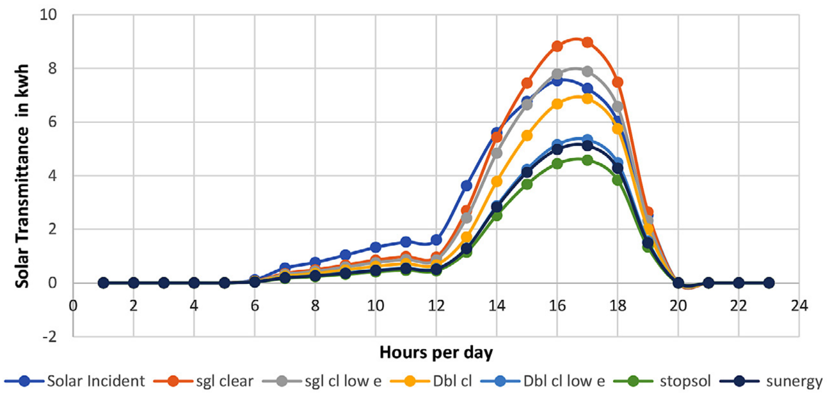

Figure 21. West facade daily exterior window gains for 80% WWR

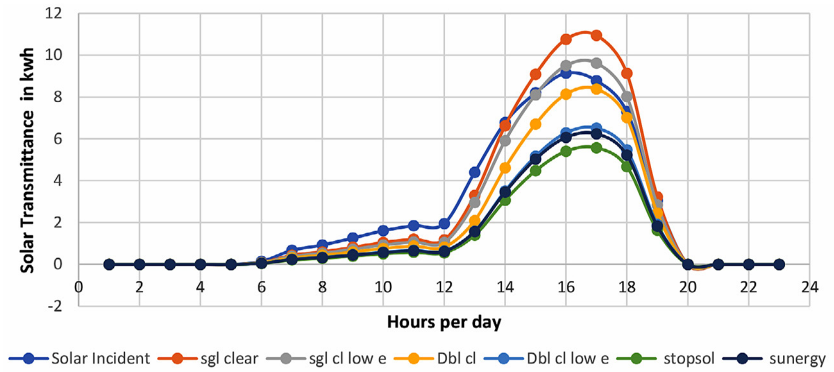

Figure 22. West facade daily exterior window gains for 100% WWR

no solar attenuation. On the other hand, Stopsol and Synergy glass reduced the transmitted gains greatly and reached to almost 50% of single clear glass compared to their initial values. The findings prove that west facades are the least favorable orientation in terms of solar heat gain, especially in the case when big areas of glazing are used (Figures 23–26).

The findings point to the fact that solar incidence and solar transmittance in buildings with glazed facades are controlled by the complex interplay of factors such as orientation of the Facade, window-to-wall ratio, glazing properties, and temporal scale (Chen et al. 2025). The results shows that even though annual and monthly evaluations are crucial for detecting critical times, daily and hourly examinations are absolutely necessary for grasping the behavior of peak solar gain that has a direct impact on thermal comfort and cooling energy requirement.

The proportional increase in incident as well as transmitted solar radiation with increasing WWR over all orientations demonstrates that the glazing ratio continually controls the solar heat gains. Nevertheless, the quantity and schedule of these gains differ greatly according to the orientation (Strobel et al., 2007). South facades show predictable and symmetrical midday peaks, which are mainly determined by solar altitude, thus making them easier to manage through architectural design. Conversely, east and west Facades encounter very uneven solar exposure caused by the low-angle solar paths, which results in intense short-duration gains that are more difficult to reduce by geometry alone.

The varying performance of different glazing types demonstrates the importance of the optical and thermal properties in regulating solar energy transmission. Single clear glazing throughout the experiment always had the highest transmitted gains, this was due to its high solar heat gain coefficient it sometimes even reached the values of the incident radiation. Low-emissivity and reflective glazing systems, such as double low-e and Stopsol, showed the best solar control, decreasing transmitted energy by 50% at peak times. Synergy glazing gave a balanced performance; it allowed moderate reductions while still giving a light flow through.

The west-facing side was identified as the leading energy-consuming orientation, especially when the ratio of windows to wall area was high,

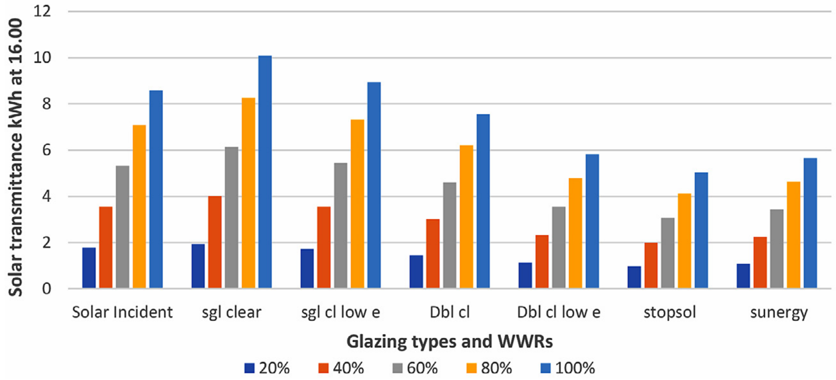

Figure 23. South solar incidence and transmittance for glazing types at different WWR at the peak hour

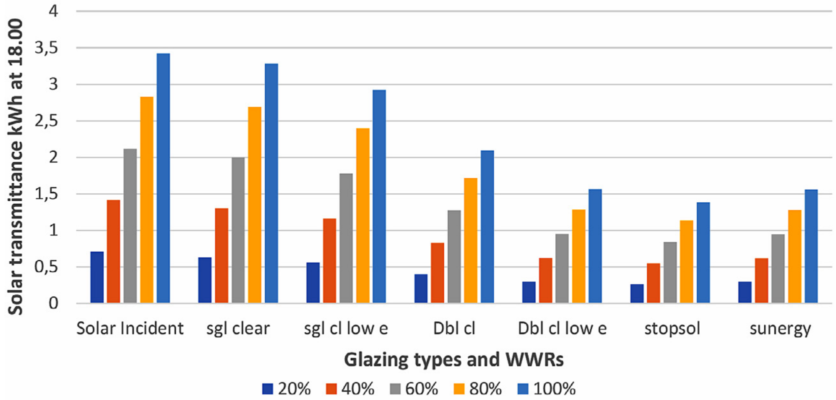

Figure 24. North solar incidence and transmittance for glazing types at different WWR at the peak hour

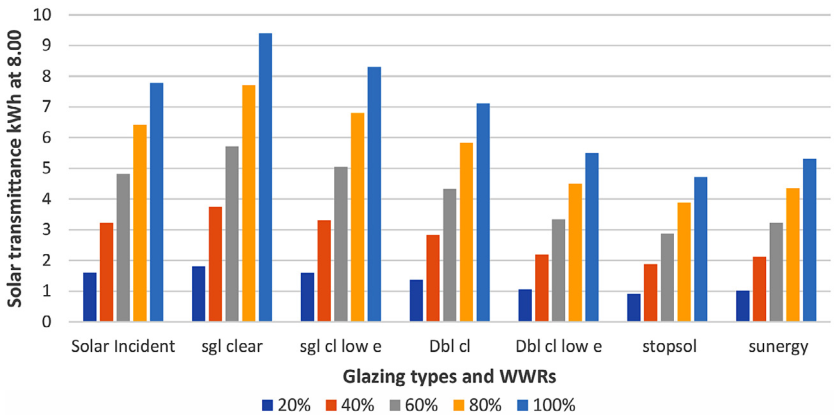

Figure 25. East solar incidence and transmittance for glazing types at different WWR at the peak hour

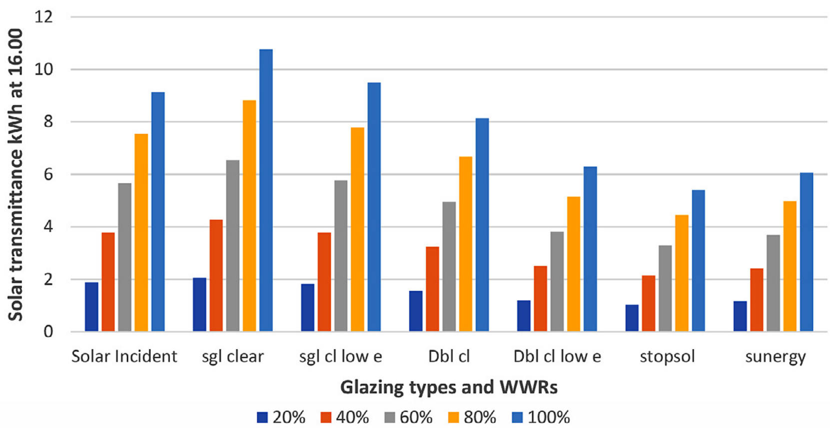

Figure 26. West solar incidence and transmittance for glazing types at different WWR at the peak hour

mainly because it was subjected to intense afternoon solar radiation for a long time. The situation could easily lead to large cooling loads and thermal discomfort if there are no good solar control solutions in place. East-facing facades, although being exposed for shorter periods, still displayed the critical morning peaks that could negatively affect indoor thermal conditions. On the other hand, north-facing Facades, which are usually not in direct sunlight, had their transmitted gains significantly increased at high glazing ratios, hence indicating that the choice of glazing is still relevant for the less-well-exposed orientations in terms of overheating risk.

The results are in line with the conclusion that peak solar conditions, which are the main drivers of building energy performance, can be hidden by the use of averaged solar radiation data (Szokolay and Gokhale, 2014). The multi-scale simulation used in this research is a powerful tool for not only spotting these peak periods but also for considering the window with its actual operation conditions during the evaluation of performance. This method becomes very important in the case of designing buildings with a lot of windows in Mediterranean and hot climates, where solar gains control is the key to energy efficiency and thermal comfort.

CONCLUSIONS

A multi-scale assessment of solar incidence as well as solar transmittance in highly glazed buildings under the climatic conditions of Palestine was given by this study, and the main focus was on the behavior of peak solar gain.

The results indicated that the increased WWR caused a rise in total irradiance and solar energy transmission that was almost proportional for all the orientations of the facade. Yet, the amount and timing of peak solar gains were greatly dependent on the orientation of the facade. The southern facades showed certain midday peaks whose heights and timings were completely sun-altitude governed, while the eastern and western Facades had very strong morning and afternoon peaks, respectively, that were caused by low-angle solar rays. Among all orientations, the western facade in particular was the most critical one for peak solar gains in almost every scenario but the north facade, which was the least favorable for penetration of solar radiation due to it being mainly surrounded by and receiving diffuse radiation, was, however, able to record significant transmission of energy increments with increasing WWRs.

The kind of glazing had a major impact on the solar transmittance during the peak period. The case of single clear glazing was the most extreme one as it led to the highest solar gains and posed a notable problem of too much heat gain in the case of big WWRs. On the other hand, double low-emissivity and solar-control glazing systems like Stopsol cut down the transmitted energy significantly, reaching a maximum of about 50% reduction in the peak hours. Synergy glazing was showing even performance, granting control of solar radiation at moderate levels while still allowing quite a bit of solar and daylight transmission.

This study's major contribution is its hierarchical analysis method, which does not depend on average solar radiation values but rather identifies the key peak conditions that influence building thermal performance and cooling demand. The results underscore the importance of pairing the right choice of glazing with controlled glazing ratios and orientation-sensitive design strategies when using large glazed facades in hot and Mediterranean climates.

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